APPENDIX F. GUIDANCE FOR PIPELINE CROSSINGS

F.1 HYDRAULIC CONSIDERATIONS FOR PIPELINE CROSSINGS OF STREAM CHANNELS

Pipeline crossings of perennial, intermittent, and ephemeral stream channels should be constructed to withstand floods of extreme magnitude to prevent breakage and subsequent accidental contamination of runoff during high-flow events. Surface crossings must be constructed high enough to remain above the highest possible stream flows at each crossing, and subsurface crossings must be buried deep enough to remain undisturbed by scour throughout passage of the peak flow. To avoid repeated maintenance of such crossings, hydraulic analysis should be completed in the design phase to eliminate costly repair and potential environmental degradation associated with pipeline breaks at stream crossings.

F.1.1 SURFACE CROSSINGS

Pipelines that cross stream channels on the surface should be located above all possible flood flows that may occur at the site. At a minimum, pipelines must be located above the 100-year flood elevation, and preferably above the 500-year flood elevation. Procedures for estimating 100-year and 500-year flood magnitudes are described in the U.S. Geological Survey's National Flood Frequency Program (Jennings et al. 1994). Two sets of relationships for estimating flood frequencies at ungauged sites in Utah are included in the NFF program: Thomas and Lindskov (1983) use drainage basin area and mean basin elevation for flood estimates for six Utah regions stratified by location and basin elevation. Thomas et al. (1997) also use drainage area and mean basin elevation to estimate magnitude and frequency of floods throughout the southwestern U.S., including five regions that cover the entire state of Utah. Results from both sets of equations should be examined to estimate the 100- and 500-year floods, since either of the relations may provide questionable results if the stream crossing drains an area near the boundary of a flood region or if the data for the crossing approach or exceed the limits of the data set used to develop the equations.

Estimating the depth of flow, or conversely the elevation of the pipeline at the crossing, may be approached a number of ways. The simplest procedure would be based solely on a field reconnaissance of the site, using basic geomorphic principles. Identification of the bank-full elevation and the active floodplain (i.e., floodplain formed by the present flow regime) provides inadequate conveyance for extreme flood events. Past floodplains/present terraces also must be identified, since these represent extreme floods in the present flow regime, especially in arid and semiarid environments. Pipeline crossings should be constructed to elevate the pipeline above the level of the highest and outermost terrace at the crossing. This level represents the geomorphic surface likely to be associated with the maximum probable flood. Since this method is entirely based on a geomorphic reconnaissance of the site, no flood-frequency analysis is required and no recurrence interval is assigned to the design elevation. While this is the simplest approach to design of the crossing, it likely will result in the most conservative estimate (i.e., highest elevation) for suspension of the pipeline.

A slightly more intensive approach to crossing design is based on the Physiographic Method described by Thomas and Lindskov (1983) for estimating flood depths at ungauged sites. The procedure utilizes regional regression equations (similar to the flood-frequency equations described above) to estimate depth of flow associated with a specified recurrence-interval flood. Flood depth is then added to a longitudinal survey of the stream channel in the vicinity of the crossing, resulting in a longitudinal profile of the specified flood. Elevation of the flood profile at the point of pipeline crossing is the elevation above which the pipeline must be suspended. While this procedure requires a field survey and calculation of actual flood depths, it may result in a lower crossing elevation (and possibly lower costs) for the pipeline. Also, since the regional regression equations estimate flood depth for specified recurrence-interval floods, it is possible to place a recurrence interval on the crossing design for risk calculations.

It may be possible to reduce pipeline construction costs associated with channel crossings even further with a water-surface-profile model of flow through the crossing site. The water-surface-profile model requires a detailed survey of both the longitudinal channel profile and several cross-sections along the stream. Design flows (e.g., 100-year and 500-year floods) are calculated for the channel at the crossing (with the regional regression equations described above) and routed through the surveyed channel reach utilizing a step-backwater analysis. The step-backwater analysis uses the principles of conservation of mass and conservation of energy to calculate water-surface elevations at each surveyed cross-section. Since the computation utilizes a detailed channel survey, it is probably the most accurate method to use; however, it is likely the most expensive method for the same reason. The step-backwater computations require an estimate of the Manning n-value as an indicator of resistance to flow, and assume fairly stable channel boundaries. Estimates of the n-value for ungauged sites are a matter of engineering judgment, but n-values typically are a function of slope, depth of flow, bed-material particle size, and bedforms present during the passage of the flood wave. Guidance is available in many hydraulic references (e.g., Chow 1959). The assumption of fairly stable channel boundaries is not always met with sand-bed channels, and is an issue of considerable importance for designing subsurface pipeline crossings as well (see below).

F.1.2 SUBSURFACE (BURIED) CROSSINGS

Since many of the pipelines are small and most of the channels are ephemeral, it is commonplace to bury the pipelines rather than suspending them above the streams. The practice of burying pipelines at channel crossings likely is both cheaper and easier than suspending them above all flood flows; however, an analysis of channel degradation and scour should be completed to ensure the lines are not exposed and broken during extreme runoff events. Without such an analysis, pipeline crossings should be excavated to bedrock and placed beneath all alluvial material.

Buried pipelines may be exposed by stream bed lowering resulting from channel degradation, channel scour, or a combination of the two. Channel degradation occurs over a long stream reach or larger geographic area and is generally associated with the overall lowering of the landscape. Degradation also may be associated with changes in upstream watershed or channel conditions impacting the water and sediment yield of the basin. Channel scour is a local phenomenon associated with passage of one or more flood events and/or site-specific hydraulic conditions that may be natural or man-caused in origin. Either process can expose buried pipelines to excessive forces associated with extreme flow events, and an analysis of each is required to ensure integrity of the crossing.

Detection of long-term channel degradation must be attempted, even if there is no indication of local scour. Plotting bed elevations against time permits evaluation of bed-level adjustment and indicates whether a major phase of channel incision has passed or is ongoing. However, comparative channel survey data are rarely available for the proposed location of a pipeline crossing. In instances where a gauging station is operated at or near the crossing, it's usually possible to determine long-term aggradation or degradation by plotting the change in stage through time for one or more selected discharges. The procedure is called a specific gauge analysis and is described in detail in the Stream Corridor Restoration manual published by the Federal Interagency Stream Restoration Working Group (1998). When there is no gauging station near the proposed pipeline crossing, nearby locations on the same stream or in the same river basin may provide a regional perspective on long-term channel adjustments. However, specific gauge records indicate only the conditions in the vicinity of the particular gauging station and do not necessarily reflect river response farther upstream or downstream of the gauge. Therefore, it is advisable to investigate other data in order to make predictions about potential channel degradation at a site.

Other sources of information include the biannual bridge inspection reports required in all states for bridge maintenance. In most states, these reports include channel cross-sections or bed elevations under the bridge, and a procedure similar to specific gauge analysis may be attempted. Simon (1989, 1992) presents mathematical functions for describing bed level adjustments through time, fitting elevation data at a site to either a power function or an exponential function of time. Successive cross-sections from a series of bridges in a basin also may be used to construct a longitudinal profile of the channel network; sequential profiles so constructed may be used to document channel adjustments through time.

In the absence of channel surveys, gauging stations, and bridge inspection reports (or other records of structural repairs along a channel), it may be necessary to investigate channel aggradation and degradation using quantitative techniques described in Richardson et al. (2001) and Lagasse et al. (2001). Techniques for assessing vertical stability of the channel include incipient motion analysis, analysis of armoring potential, equilibrium slope analysis, and sediment continuity analysis. Geomorphic indicators of recent channel incision (e.g., obligate and facultative riparian species on present-day stream terraces elevated above the water table) also may be helpful for diagnosing channel conditions.

In addition to long-term channel degradation at the pipeline crossing, local scour of the crossing must be addressed for pipeline safety. Local scour occurs when sediment transport through a stream reach is greater than the sediment load being supplied from upstream and is usually associated with changes in the channel cross-section. Local scour can occur in natural channels wherever a pipeline crosses a constriction in the channel cross-section (contraction scour). Equations for calculating contraction scour generally fall into two categories, depending on the inflow of bed-material sediment from upstream. In situations where there is little to no bed-material transport from upstream (generally coarse-bed streams with gravel and larger bed materials), contraction scour should be estimated using clear-water scour equations. In situations where there is considerable bed-material transport into the constricted section (i.e., for most sand-bed streams), contraction scour should be estimated using live-bed scour equations. Live-bed and clear-water scour equations can be found in many hydraulic references (e.g., Richardson and Davis 2001). In either case, estimates of local scour in the vicinity of the pipeline crossing must be added to the assessment of channel degradation for estimating the depth of burial for the crossing.

Even in the absence of contraction scour, local scour will still occur in most sand-bed channels during the passage of major floods. Since sand is easily eroded and transported, interaction between the flow of water and the sand bed results in different configurations of the stream bed with varying conditions of flow. The average height of dune bedforms is roughly one-third to one-half the mean flow depth, and maximum height of dunes may nearly equal the mean flow depth. Thus, if the mean depth of flow in a channel was 5 feet, maximum dune height could also approach 5 feet, half of which would be below the mean elevation of the stream bed (Lagasse et al. 2001). Similarly, Simons, Li and Associates (1982) present equations for antidune height as a function of mean velocity, but limit maximum antidune height to mean flow depth. Consequently, formation of antidunes during high flows not only increases mean water-surface elevation by one-half the wave height, it also reduces the mean bed elevation by one-half the wave height. Richardson and Davis (2001) report maximum local scour of one to two times the average flow depth where two channels come together in a braided stream.

Pipeline crossings that are buried rather than suspended above all major flow events should address all of the components of degradation, scour, and channel-lowering due to bedforms described above. In complex situations or where consequences of pipeline failure are significant, consideration should be given to modeling the mobile-bed hydraulics with a numerical model such as HEC-6 (U.S. Army Corps of Engineers 1993) or BRI-STARS (Molinas 1990). The Federal Interagency Stream Corridor Restoration manual (FISRWG 1998) summarizes the capabilities of these and other models, and provides references for model operation and user guides where available.

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